CRM D0007793.A2/Final
March 2003

At-Sea Experimentation with Joint Venture, October 2001 through September 2002

George M. Stewart

CNA
4825 Mark Center Drive • Alexandria, Virginia 22311-1850

Approved for distribution: March 2003

Ralph W. Passarelli

Dr. Ralph W. Passarelli
Director, Theater Operations Team
Operations Evaluation Group

This document represents the best opinion of CNA at the time of issue.
It does not necessarily represent the opinion of the Department of the Navy.

Distribution limited to DOD agencies. Specific authority: N00014-00-D-0700.
For copies of this document call: CNA Document Control and Distribution Section at 703-824-2123.

Contents

Introduction and summary

Background

The High-Speed Vessel (HSV) project is a joint effort by the U.S. Army, U.S. Navy, U.S. Marine Corps, and the Naval Special Warfare Command (on behalf of U.S. Special Operations Command). The goal of the project is to explore the concepts and capabilities associated with commercially available advanced hull and propulsion technologies integrated with advanced communications technology. This report covers experimentation with *Joint Venture*, a leased high-speed car ferry with temporary modifications (see figure 1), between October 2001 and the end of Millennium Challenge 2002 in September 2002. Experimentation continues: the lease of *Joint Venture*, the HSV-X1, has been extended, and a new ship, the HSV-X2, has been leased.

Figure 1. *Joint Venture,* HSV-X1

The Navy Warfare Development Command (NWDC) asked the Center for Naval Analyses to help document and synthesize the results of at-sea experimentation with *Joint Venture*. This document is the result. It summarizes the detailed information available in a series of reports. It also draws on material from the lease of a similar ship, *WESTPAC Express*, by the Military Sealift Command (MSC) in support of administrative movements by III MEF.

Since the U.S. Army has an existing Operational Requirements Document (ORD) for a Theater Support Vessel, it structured its events as demonstrations of the ship's ability to meet ORD requirements.

This document focuses on potential Naval applications. The Navy does not have an existing ORD for such a ship. Therefore, the Naval portion of the HSV project began with the technologies developed by the commercial sector, and asked the question, "How might these technologies be useful for military applications?" This approach is suitable for exploratory research, but it is somewhat different from the traditional acquisition model, and readers should keep it in mind when reading this report.

What did we do?

Joint Venture operated under U.S. Navy Administrative Control (ADCON) except for the operations in support of Operation Enduring Freedom and the redeployment of elements of a Stryker Brigade during Millennium Challenge 02. For those events, the U.S. Army had ADCON of the ship. Table 1 lists the operations, experiments, exercises, and tests conducted by *Joint Venture*. The individual experiment partners were responsible for their experiments. They ranged from tests/demonstrations of interoperability with other platforms to experimentation with potential concepts of operation.

What did we learn?

As a result of these events, we can draw some tentative conclusions about the overall utility of a high-speed vessel for military operations. We also learned more about the potential suitability of this particular type of HSV (*Joint Venture*) in a military environment.

Table 1. Joint Venture events, October 2001–September 2002

Event	Dates	Test agencies	Major activities
Static loading experiments	18, 25 October	MCCDC, MCWL	Static load test of USMC equipment
Sea-keeping and flight certification	30-31 October	NSWCCD, NAVAIR	Flight certification, sea trials
NUWC LOE	7-8 November	NUWC	High-speed sensor deployment
SOF interoperability LOE	13-16 November	NAVSPECWARCOM, NSWG 2	Interoperability with SEAL mobility platforms
USMC load-out experiments	27-30 November	MCCDC, MCWL	Load/unload experiments of USMC equipment
Mine warfare LOE	2-6 December	NWDC	MIW command and control, MCM support
Bulk fuel co. movement	10-11 January	MCCDC, MCWL	Intra-theater movement
JTFEX 02-1	14-16 January	COMSECONDFLT, NWDC	MIW command and control, MCM support, SOF support
Battle Griffin and Strong Resolve	4 February - 15 March	NWDC, MCCDC, MCWL	Trans-Atlantic deployment, intra-theater movement of units, mining,
Operation Enduring Freedom	20 March - 13 July	CENTCOM, CASCOM	Intra-theater lift of supplies, trans-Pacific redeployment
Millennium Challenge 02 and Fleet Battle Experiment Juliet	21 July - 13 August	NWDC, MCCDC, MCWL, NAVSPECWARCOM, CASCOM	MIW command and control, MCM support, SOF command and control, SOF support, ship-to-objective-maneuver, brigade redeployment

The following bullets summarize the major findings. A more detailed explanation and supporting data for each finding are in the body of the report. The reports forming the basis for these findings (references [1–27]) contain a wealth of information on other topics ranging from provision of food service for the crew to Navy officers' initial impression of an HSV's warfighting potential for ASUW. The findings presented below meet two criteria: (1) We judged them to be of major importance to future HSV testing/usage; and (2) there is a sizable body of analytical data that support the finding.

- *Joint Venture* demonstrated that large ships (100 meters long) based on a wave-piercing catamaran hull have sufficient range to shift quickly between theaters in an independent movement or to deploy with a battlegroup or an amphibious ready group. In practice, such transfers will probably require that the ship carry minimal cargo.

- *Joint Venture* demonstrated the ability to precisely deploy sensors and weapons at high speed. This could be tactically useful in deploying large numbers of mines (or sensors of equivalent weight) rapidly.

- HSVs are competitive with air transport for intra-theater lift of ground units and their equipment.

- *Joint Venture* and *WESTPAC Express* demonstrated efficient load and off-load of both wheeled and tracked rolling stock. Vehicles up to the size of 5-ton trucks were off-loaded at a rate of two to three vehicles per minute. Containers, palletized break-bulk cargo, and helicopters have also been successfully loaded on board the ships, but with less efficiency. To fully exploit the speed of an HSV for intra-theater lift, the loading process should be similarly engineered for speed.

- *Joint Venture* demonstrated the ability to support daytime takeoff and landing of several SH-60 and CH-46 series helicopters. The helicopter deck was used to transfer passengers (often for VIP visits) and to move small amounts of cargo. The lack of a helicopter refueling system and the need to move cargo to and from the flight deck by hand, limited the usefulness of *Joint Venture* as a surrogate for testing HSV helicopter support concepts.

- *Joint Venture* demonstrated the ability to launch and recover small boats and autonomous vehicles in seas up to 5 feet. This capability should be improved to enhance the ship's ability to develop or test tactics and operational concepts. Launch systems and procedures should be developed that allow the launch and recovery of larger vehicles in higher sea states without requiring the HSV to come to a near stop or use a manned support boat in the water.

- The Joint Operations Center (JOC) on *Joint Venture* proved capable of sequentially supporting two different command staffs charged with planning for and controlling tactical operations with minimal time required to switch between roles.

- During the experiments, the Navy exercised a number of missions aboard *Joint Venture*. The effort required to switch between missions is better described as requiring a change-out of embarked personnel and equipment rather than as swapping modules in the same sense that existing modular combatants (such as the Danish Flyvefisken-class ships) swap out modules. Change-outs between various mission loads during experimentation took minimal time. During the various experiments, reconfiguration always took less than a half-day and in most cases required only a few hours. The experiments demonstrated the potential for reconfiguration and the ease with which a ship could be reconfigured. However, the desirability of modular combatants is still to be determined, by issues other than the capability to quickly and efficiently reconfigure a ship. These issues are primarily the potential cost savings and the impact of reconfiguration on mission performance. They are best addressed in design studies and not in at-sea experimentation.

- In a fully loaded condition, operations by *Joint Venture* were unaffected in seas up to a significant wave height[1] of approximately 8 feet. In higher seas, significant amounts of slamming occurred when *Joint Venture* headed into the waves at speeds in

1. Significant wave height is defined as the height reached by 30 percent or more of the waves.

excess of 10–15 knots. The speed at which the high-speed slamming regime began depended upon the wave period and loading of the ship. The slamming produced a rough ride (described by ship-riders as similar to an aircraft in turbulence) and in some instances induced structural damage. This places constraints on, but does not eliminate, operations by *Joint Venture* in seas between the 8-foot wave height where slamming starts and the 16-foot wave height limit imposed by the classification society. It is possible that a redesign of the ship could either mitigate the impact of slamming or produce a larger regime of unrestricted operations.

- *Joint Venture* demonstrated the ability to support the tactical movement of intact units up to the size of two companies into ports with depths as shallow as 18 feet with restricted maneuvering room, and to quickly discharge the units without the aid of local pilots.

- *Joint Venture* demonstrated the ability to conduct periodic operations at sea for periods of up to 1 week. Factors limiting the endurance of the test-bed ship include the ship's small crew size, a requirement to visit port to take on fuel or supplies, and maintenance requirements.

- At times, *Joint Venture's* crew was judged too small to support some sustained operations. When operating under Navy Administrative Control, *Joint Venture* was crewed by 31 personnel—4 Navy officers, 18 Navy enlisted, 3 Army warrant officers, 3 Army enlisted, 2 enlisted provided by NAVSPECWARCOM, and 1 Marine enlisted. That crew size sometimes proved to be inadequate for routine requirements such as manning all force protection positions when in port. It also proved to be less than optimal for supporting the intense operating pace prevalent during most of the experiments.

What remains to be learned?

While we have made progress in understanding the potential utility and suitability of a ship such as *Joint Venture* for military purposes, significant work remains to be done. Much of that work cannot be accomplished through at-sea experiments; instead, other means of investigation, such as engineering studies, wargames, and operations analysis, will be required.

In addition, after the experimentation with *Joint Venture* began, the Navy began studying options for a Littoral Combat Ship (LCS). An HSV design is one of the options under consideration. To maximize the value of both the experimentation and the ongoing LCS study, the two efforts should be integrated to ensure that future experiments are relevant to the issues being considered by the study team.

A focused program of study that integrates at-sea tests with analysis conducted on shore would help validate the conclusions drawn by either experimentation or analysis. For example, at-sea tests provide an invaluable means of validating the modeling parameters and assumptions made by engineering studies and operations analysis. Wargames and studies could also identify the most fruitful HSV concepts of operation and help identify those CONOPS issues best resolved through at-sea tests.

Issues for testing and analysis

The project goals

The goals of the HSV project are to:

- Explore the potential military utility and suitability of commercially available advanced hull and propulsion technology.
- Explore the potential military utility of a reconfigurable vessel with an integrated C4I suite.

Here we give a broad overview of expected characteristics of an HSV and a summary of top-level questions that cut across several potential military uses of an HSV.

Expected characteristics of an HSV

INCAT, the manufacturer of *Joint Venture*, developed its line of wave-piercing catamarans for the fast car-ferry market. Other commercial manufacturers have developed fast car ferries based on slightly different technologies for the same market.

The following HSV characteristics are associated with military utility:

1. High speed
2. High payload fraction
3. Shallow draft
4. Ability to self-deploy
5. C4I support for command and control
6. Ability to be reconfigured
7. Ability to launch and recover air, surface, and subsurface vehicles.

Characteristics 1–4 are generally present in the larger variants of the fast-speed commercial car ferries. They relate mainly to the first experiment goal: that of exploring the potential military utility and suitability of commercially available advanced hull and propulsion technologies.

Table 2 shows how *Joint Venture* compares to three other ships, an ALGOL-class fast sea-lift ship used for inter-theater lift, a Cyclone-class coastal patrol ship, and an Oliver Hazard Perry-class frigate.

Table 2. Comparison of *Joint Venture* with three other ship classes[a]

	Joint Venture	ALGOL *class*	Cyclone *class*	Oliver Hazard Perry *class*
Top speed (kts)	45	33	35	29
Displacement, fully loaded (short tons)	1,872	55,425	331	3,658
Max. cargo (short tons)	308[b]	25,000	N/A	N/A
Range, fully loaded max. fuel (n.mi.)	3,000 @ 35 kt	12,200 @ 27 kt	595 @ 35 kt	4,200 @ 20 kt
Manning	31 mil.	49 civ.	30 mil.	214 mil.
Draft	13′	36′ 9″	8′	21′ 9″

a. Data for comparison ship classes taken from *Periscope* at *www.periscope.ucg.com.*
b. Maximum cargo allowed with ship fully fueled. If only the day tanks are filled, cargo can increase to 672 short tons; however, the maximum range at 35 knots then decreases to 1,100 n. mi.

Table 2 provides a point of reference for comparing the capabilities of the *Joint Venture* hull form with other types of ships. The ALGOL-class fast sea-lift ship is a representative of a high-performance cargo ship designed to carry cargo across ocean basins. The combination of its speed and capacity provides for the fast movement of large amounts of cargo from one deep-draft port to another. *Joint Venture,* however, can access far more ports than an ALGOL-class ship, and its cargo capacity, while smaller, is still large enough to move about two companies of troops with their equipment [29-30].

The Cyclone-class coastal patrol ship and the Oliver Hazard Perry-class frigate are two combatants that bracket *Joint Venture* in terms of size. *Joint Venture* has a higher top speed than either, and has much more endurance and carrying capacity than the Cyclone-class coastal patrol ship. For example, one mission for the Cyclone class is to carry Naval Special Warfare personnel and their mobility platforms (typically an 11-meter RHIB and CRRC). The Cyclone-class coastal patrol ship can carry a maximum of 8 special warfare personnel, whereas, in its present configuration *Joint Venture* could berth at least 52 special warfare personnel.

Characteristics 5–7 could be designed into any number of hull forms. They relate mainly to the second goal: examining the potential military utility of a reconfigurable ship with an advanced C4I suite.

While not listed as a characteristic, it is worth noting that commercial variants of these ships are considerably cheaper than most military combatants. Car ferries the size of *Joint Venture* are available on the open market for 40 to 60 million dollars. While costs for a militarized version would depend upon the vessel's concept of operations, operating environment, specific systems installation, and other required modifications, the moderate base cost of the ship has generated attention.

More information about the detailed characteristics of *Joint Venture* is available in appendix A and in references [1–3].

Summary of important issues

These important issues include the following questions:

- Is the performance of a military mission enhanced by any of the special characteristics of an HSV? (That is, do they bring more performance for the cost or a new capability?) These characteristics are its:
  - — High speed
  - — Shallow draft
  - — High payload fraction
  - — Ability to self-deploy.

- Is the mission or cost performance enhanced by the ability to reconfigure the ship with modules?
- Is a wave-piercing catamaran such as *Joint Venture* with its current limitations generally suitable for Naval operations? If not, what enhancements are required in the following areas:
  - Seakeeping (weather limitations)
  - Durability (expected service life, mean time between casualties)
  - Endurance (continuous operating time on station)
  - Operating cost (fuel, maintenance, other)
  - Survivability.
- For a given military mission, what elements of support can we expect ships like *Joint Venture* to provide? If structural modifications are required in order to enhance the ship's military utility, what impacts would these modifications have on important ship characteristics such as speed and payload?
- For a given military mission, can ships like *Joint Venture* provide an appropriate level of support (hotel services, work spaces, C4I support, etc.) for the staff charged with the activity?
- For a given military mission, can we expect to design an HSV with suitable interfaces (ship-to-ship, ship-to-pier, ship-to-air, etc.) to support the operation? Would the footprint of the interface have an adverse impact on ship performance?

These issues fall into two broad categories: utility ("What is a ship like this good for?") and suitability ("Will it be practical to operate a ship like this for military purposes?"). The next two sections provide top-level summaries of the experimental results organized according to these questions of military utility and suitability.

Utility of HSVs for military operations

Here we summarize the findings of recent at-sea tests that addressed the broad issue, "What potential military utility does an HSV offer?" We then close with a summary of the most important areas for further investigation.

Advanced hull form capabilities were demonstrated in at-sea testing

Self-deployment at high speed

Finding: Joint Venture *demonstrated that large ships (100 meters long) based on a wave-piercing catamaran hull have sufficient range to shift quickly between theaters in an independent movement or to deploy with a battlegroup or amphibious ready group. In practice, such transfers will probably require that the ship carry minimal cargo. See [5–7, 22–25].*

Joint Venture demonstrated the capability of a wave-piercing catamaran to deploy from CONUS to forward locations. Table 3 shows the movements conducted by *Joint Venture* to and from CONUS.

Table 3. *Joint Venture* deployment and return transits

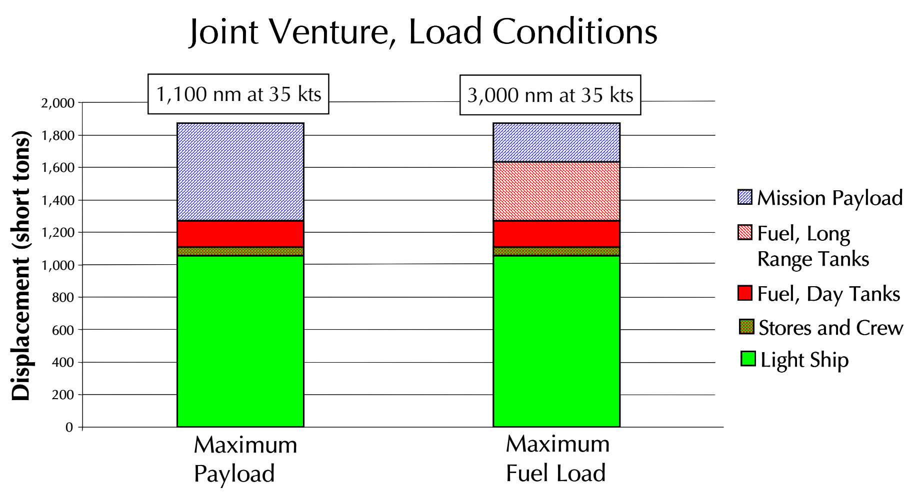
Departure		Arrival		Distance	Average speed
Port	Date	Port	Date	(n.mi.)	(knots)
Moorehead City, NC	6 February	Rota, Spain	13 February	3,594	27
Djibouti	21 June	San Diego, CA	13 July	13,226	24[a]

a. Includes time spent for port stops in Diego Garcia, Singapore, Kwajalein, and Honolulu. Typically, the ship spent one day in port at each stop taking on fuel and supplies. Minimum time spent in any of the ports en route was 8 hours. Underway speed averaged 28 knots. In both transits, the speed of the ship while underway varied from 15 to 38 knots in accordance with local conditions and the ship's schedule.

During the transit to Rota, *Joint Venture* carried about 100 short tons of cargo (eleven M198 howitzers and a forklift) and 47 embarked personnel. During the transit from Djibouti to San Diego, *Joint Venture* carried no cargo and from two to four embarked personnel, depending upon the leg of the transit.

As with all ships, the maximum one-way unrefueled cruising range of *Joint Venture* is strongly dependent upon the speed of transit and the amount of cargo carried. If less cargo is carried, more of the ship's maximum deadweight can be devoted to fuel. In addition, the ship is more fuel efficient at lighter loadings, though this consideration is secondary to the primary trade-off between carrying fuel and carrying cargo. Figure 2 (adapted from [5]) shows this trade-off.

Figure 2. Mission payload vs. fuel



When mission payload is maximized (about 600 short tons), *Joint Venture* has a maximum one-way range of about 1,100 n.mi. at 35 knots. When *Joint Venture* carries the maximum amount of fuel, it is limited to about 308 short tons of mission payload, but the operating range triples. Another way to increase the operating range is to slow down. Slowing to 15 knots and operating on only two of the four water-jet engines would double both the above range estimates.

Table 4 compares total deployment times for independent deployments at speeds of 25 and 35 knots. This chart assumes that the ship stops every 3,500 n.mi. or so to take on fuel in a one-day port visit. Where canal transits are involved, an additional day is added to the transit time to reflect transit of the canal. The "25 knot" column is representative of the performance demonstrated by *Joint Venture* during its deployment to Europe and return from the west coast of Africa. The "35 knot" column would be appropriate for ships meeting the design specifications of the larger (110+ meter) catamarans currently available commercially. The times for these independent deployments are considerably shorter than those achieved by today's battlegroup and amphibious ready group deployers. Thus, if desired, an HSV like the *Joint Venture* could carry at least 200 short tons of cargo and easily keep up with a deploying battlegroup or amphibious ready group, if it could be refueled at sea.

Table 4. Illustrative deployment times (days)

From	To	Transit speed 25 knots	Transit speed 35 knots	Port stops
Norfolk	Naples	8.2	6.2	Rota
Naples	Kuwait	9.3	7.2	Port Said (Suez Canal)
San Diego	Yokohama	9.4	7.0	Dutch Harbor
Honolulu	Yokohama	5.7	4.0	None
San Diego	Bahrain	22.3	16.8	Dutch Harbor, Yokohama, Singapore
Honolulu	Bahrain	17.9	13.4	Apra, Singapore
Norfolk	San Diego	9.8	7.6	Panama (Panama Canal)

High-speed precise deployment of weapons and sensors

Finding: Joint Venture *demonstrated the ability to precisely deploy sensors and weapons at high speed. This could be tactically useful in deploying large numbers of mines (or sensors of equivalent weight) rapidly. See references [6, 11, 15–17, 21–22, 24].*

Joint Venture conducted a number of high-speed experiments in the deployment of environmental sensors and mines:

- A deployment of 48 expendable bathythermograph buoys (XBTs) at speeds of up to 40 knots to map a warm-water incursion of the Gulf Stream near Newport, RI. The XBTs were deployed at rates of one XBT every 3–5 minutes. While the XBTs had not been designed with rapid deployment in mind, only three out of the 48 buoys malfunctioned.
- Deployment of eight expendable bottom penetrometers (XBPs) at speeds near 40 knots, to map bottom topography near Panama City, Florida.
- Deployment of five mine shapes at a speed of 40 knots, also near Panama City, Florida. The mines were deployed at a rate of about one mine per minute.
- Deployment of six mine shapes at a speed of about 36 knots off the Virginia Capes during JTFEX 02-1.
- Laying of 30 German Mk 36 mines in an irregular pattern with 30 waypoints at 34+ knots.

The ship's navigation system and simple coordination procedures enabled accurate placement of the mines. After calibrating the procedures during the first mine drop at Panama City, the crew laid subsequent mines within 3–30 yards of the intended drop point. Prior to the mining run, mines were deployed on a pallet near the end of the ship. During the mining run, ship's crew hoisted the mines one at a time by the stern crane over the water and then dropped the mine on signal. This process was capable of deploying about one mine per minute.

While in some situations aircraft can deploy sensors and mines faster, deployment from a fast surface craft offers two major advantages:

First, *Joint Venture* can lay mines more accurately. Current systems and procedures for dropping mines from the air offer accuracies of a few hundred yards at best. Operations with *Joint Venture* demonstrated that a ship with a modern navigation system can place mines far more accurately. This is an important tactical consideration if one's own forces must later operate near the minefield.

Second, *Joint Venture* can carry and lay 20 to 30 times more mines than an aircraft can lay in a single sortie. Mines are heavy and the Navy's air mining platforms, such as the P-3C, can carry at most five or six at a time. Thus a single mine-laying mission by a surface ship could replace multiple aircraft sorties. If the numbers of aircraft available for mining are restricted, a field of a few hundred mines could probably be laid more quickly with a fast surface ship.

Economical, high-speed lift of intact units

Finding: HSVs are competitive with air transport for intra-theater lift of ground units and their equipment.[2]

High-Speed Vessels with cruising speeds of 35–40 knots are slower than aircraft (the C-5's nominal transit speed is around 400 knots), but the HSV's greater capacity tips the cost-benefit ratio in favor of the ship for many common scenarios.

For example, using a leased 101-meter AUSTAL high-speed ferry,[3] III MEF recently moved 818 Marines with 42 HMMWVs, eight M101 trailers, three 5-ton trucks, one M105 trailer, two LAVs, one AAV, one 10-ton fork lift and 30 quadruple containers (321 long tons) from Okinawa to Yokohama. The transit took 28 hours. Loading and unloading the force consumed another 3 hours. Moving the same force with aircraft would have required five C-5 sorties.

2. Material for this finding and others relating to *WESTPAC Express* derives from internal working papers provided by III MEF and its CNA field representative, Dr. Stephen Guerra, and correspondence with the WESTPAC Express Combat Cargo Officer. Information relating to operations of *Joint Venture* for intra-theater lift missions is contained in reference [24].

3. The AUSTAL ferry boat, *WESTPAC Express*, has a catamaran semi-SWATH- style hull vice the wave-piercing design of *Joint Venture*. It also has both a stern and bow ramp vice the stern quartering ramp of *Joint Venture*. Its range, top speed, draft, and interior design (large open spaces on the passenger and vehicle decks) are similar to *Joint Venture*'s.

The Military Sealift Command has a long-term lease on *WESTPAC Express*, and charges III MEF about $52,000 per 24 hours of underway time. The cost includes fuel, port fees, and salaries. Thus, the cost to the command for the one-way 31-hour movement (includes transit + load/unload times) is about $67,000. The cost to III MEF for C-5 lift would have been $16,600 per hour. With a nominal two-hour one-way flight time, five one-way C-5 sorties would have cost the command about $166,000.[4]

Which method of lift would generally close the unit first? That depends totally on the numbers of aircraft participating in the lift. For the Okinawa–Yokohama example, a single aircraft shuttling back and forth would require about 40 hours of flight time to conduct ten sorties. Adding time for loading, unloading, crew rest, and maintenance would make the total time much longer. Since movement by aircraft requires separating the Marines from their equipment and moving fewer passengers per sortie, additional time is required at the receiving end to receive and organize the force so that it is ready for operations. The movement by ship will clearly close the unit first in this example if it competes with a single aircraft.

In theory, multiple aircraft could close the force faster, but in practice competition for intra-theater lift resources often causes the process to stretch out. In past years, III MEF typically had to allocate about 2 weeks for a similar number of Marines to make administrative movements to and from exercises in Korea or Japan. Use of *WESTPAC Express* has saved III MEF both money and time compared to airlift. Additional time is saved on the overall transit process when the time to reform the unit and marry it up with its equipment is included.

During Fiscal Year 2002, III MEF used *WESTPAC Express* for 45 administrative movements, to move a total of over 18,000 passengers and 12,800 short tons of vehicles, helicopters, and containerized/palletized cargo.

---

4. This reflects the cost that would have been billed to III MEF. Since some of TRANSCOM's costs are subsidized (for example, user fees do not cover procurement costs for new aircraft), the actual cost to the U.S. Government would be somewhat higher.

Joint Venture also conducted intra-theater lift missions while in CENTCOM. In contrast to the *WESTPAC Express,* which moved intact units to and from exercises for III MEF, *Joint Venture* primarily moved cargo during its CENTCOM deployment. Between April and June 2002, *Joint Venture* moved 131 passengers and roughly 1,700 short tons of cargo in 15 lift missions. The Army estimated the operating cost (fuel, maintenance, salaries, consumed stores, etc.) of *Joint Venture* while performing these lift missions at roughly $1,160 per hour. This cost does not include many overhead items contained in the rates that MSC charges III MEF for use of *WESTPAC Express* (lease fee, insurance, port fees, contracting support, etc.); thus, the MSC rates quoted earlier are probably a more accurate reflection of the overall cost of operating an HSV.

In summary, potential HSV designs represent a compromise between fast aircraft with limited cargo capacity, and slower, less expensive (per displacement ton) ships with a much larger cargo capacity. Experience with *WESTPAC Express* (and, to a lesser degree, *Joint Venture*) indicates that HSVs could fill a useful niche for the military in an intra-theater lift mission. Defining the boundaries of that niche will require a cost-benefit analysis that is beyond the scope of the current experimentation program with *Joint Venture.*

Existing ship-to-pier interface works best for rolling stock

Finding: Joint Venture *and* WESTPAC Express *demonstrated efficient load and off-load of both wheeled and tracked rolling stock. Vehicles up to the size of 5-ton trucks were off-loaded at a rate of two to three vehicles per minute. Containers, palletized break-bulk cargo, and helicopters have also been successfully loaded on board the ships, but with less efficiency. To fully exploit the speed of an HSV for intra-theater lift, the loading process should be similarly engineered for speed. See references [6-8, 12-13, 18, 22-23, 25-27].*

Loading times onboard *Joint Venture* and *WESTPAC Express* were sensitive to the type of cargo loaded. In particular, loading helicopters for transit (only done aboard *WESTPAC Express*) proved to be time consuming.

Examples of load/unload times of lift missions conducted for *administrative* purposes include:

- *WESTPAC Express*: HQ Battery, 12th Marines: 818 passengers, 33 vehicles, 15 trailers, 9 quadcons, and other break-bulk cargo: loading time, 2.5 hours; unloading time, 0.75 hour.

- *WESTPAC Express*: 1st Battalion, 3rd Marines: 654 passengers, 50 vehicles, 8 trailers, 16 quadcons, and 25 pallets: loading time, 3.5 hours.

- *Joint Venture*: Bulk Fuel Company, 2nd Engineer Support Battalion: 229 passengers, 7 vehicles, 2 trailers, 2 equipment movers, 12 pump units, 3 hose units, 36 storage tank assemblies, 4 beach load assemblies, 5 light sets, 15 palcons, 4 quadcons, and other break-bulk items: loading time, 4.25 hours; unloading time, 7.3 hours.

- *WESTPAC Express*: Guam SPMAGTF: passengers (number not reported), 38 vehicles, 5 AH1W helicopters, 2 UH1N helicopters: on-load in Okinawa, 16.3 hours; off-load in Guam, 15.25 hours; on-load in Guam, 10.6 hours; off-load in Okinawa, 13.3 hours.

- *Joint Venture*: 40 German Mk 36 exercise mines: on-load, 2.0 hours, with an additional 30 minutes to secure for sea; off-load of 10 mines, including time to moor at the weapons station, 29 minutes. The other 30 mines were laid.

By way of comparison, transiting 1,000 n.mi. at the preferred cruising speed of 35 knots requires 28 hours. Thus, for the transport of helicopters, moving the aircraft on and off the ship could consume more time than the transit. This is due to the complexity of the process. In order to load helicopters on board *WESTPAC Express*, the crew had to support the ship's bow ramp to a horizontal position by first using fork-lifts on the pier, then using a crane to lift the helicopter on the now-horizontal ramp. (See figure 4.) If the ramp was not horizontal, the helicopter blades would not clear the entrance. The crew then fitted wheels to the helicopter's skids and towed the helicopter into position on the vehicle deck.

Figure 3. Loading a helicopter on board *WESTPAC Express*. Note the use of forklifts to support and hold the ramp horizontal.

Rolling stock was moved on and off both *WESTPAC Express* and *Joint Venture* with efficiency. Both *Joint Venture* and *WESTPAC Express* successfully embarked a wide variety of wheeled and tracked vehicles. Vehicles up to the size of 5-ton trucks or AAVs traversed the ramp and maneuvered inside the vehicle deck. In timed load tests, III MEF was generally able to load/unload HMMWVs at a rate of two to three vehicles per minute. During Battle Griffin, *Joint Venture* demonstrated the ability to combat load and discharge light wheeled forces at the same rate of two to three vehicles per minute. For example, after entering the port area in Okanger, Norway, *Joint Venture* was ready to load within 9 minutes.[5] Subsequently, the *Joint Venture* combat loaded 108 Marines of the 2nd Marine Regiment, five Norwegian home guard, and 25 vehicles (15 HMMWVs, 5 LAVs, 4 BV-206 CSS Detachment vehicles, and 1 Norwegian light tactical vehicle) in 59 minutes. Discharge of the vehicles took 25 minutes.

5. Includes time in which the ship entered into restricted maneuvering, pivoted 180 degrees to position stern quartering ramp on the pier, moored, lowered the ramp, and readied itself to on-load vehicles and personnel.

Vehicles with large trailers (for example, a 5-ton truck with an attached Mk 870A1 trailer) loaded less efficiently. The difficulties started with *Joint Venture*'s stern quartering ramp, which formed kinks (see figures 4 and 5) and required the trailer to make an immediate turn at the top of the ramp.[6] Once on board, numerous support stanchions restricted the mobility of the trailer and forced loading of the trailer athwart ship, which obstructed selective off-loading.

Figure 4. Wheels of Mk 870 trailer leave ground due to kinks in *Joint Venture* ramp. Had trailer been fully loaded, axle load limits could have been violated.

While the ability to load/unload rolling stock generally proved to be adequate for the experiments, the operators suggested several design changes to enhance performance for military operations:

- Redesign the stern quartering ramp on *Joint Venture* to eliminate "kinks" in the incline of the ramp, strengthen the ramp, and widen the ramp.

6. *Joint Venture* can also load/off-load using a portable stern ramp deployed by the rear gantry crane. In a year of experimentation, this ramp was used once due to pier availability and construction. The stern quartering ramp shown in the figures is preferred because it allows *Joint Venture* to moor alongside the pier.

Figure 5. View of the *Joint Venture's* stern quartering ramp during an off-load in Norway. Note the wooden forms near the top of the ramp to smooth out kink in the ramp incline.

- Eliminate the liftable deck and its supports, in order to increase maneuverability on the vehicle deck and save weight for other design changes. (Removal of a similar hoistable deck from *WESTPAC Express* provided the weight allowance for numerous small design changes and an increase in cargo capacity of about 20 short tons.)

These proposed changes seem to be worthy of consideration and could be easily implemented. A study should be done to find the best method for bringing containers, pallets, and other types of cargo aboard. While loading containers and pallets into trucks decreases the load and off-load times, it also reduces the amount of mission-essential cargo that can be carried if the trucks are not needed at the receiving end. A study considering employment of HSVs as high-speed lighters showed that with current technology, cargo load and unload times could be expected to be roughly comparable to transit times for intra-theater distances (1,000 n.mi. or so)[28]. If an HSV's speed is to be fully exploited for intra-theater lift, the loading process should be similarly engineered for speed.

Ability to conduct limited air operations

Finding: Joint Venture *demonstrated the ability to support daytime takeoff and landing of several SH-60 and CH-46 series helicopters. The helicopter deck was used to transfer passengers (often for VIP visits) and to move small amounts of cargo. The lack of a helicopter refueling system and the need to move cargo to and from the flight deck by hand, limited the usefulness of* Joint Venture *as a surrogate for testing HSV helicopter support concepts. See references [6-7, 9-10, 17, 21, 26-27].*

The ability to conduct air operations greatly enhances the mission flexibility of any ship. In the near future, no other single system that the ship could carry will offer the capabilities offered by helicopters. Some autonomous vehicles may eventually develop to the point where they are competitive with helicopters. These include Unmanned Underwater Vehicles such as the Battlefield Planning Autonomous Underwater Vehicle (BPAUV), Unmanned Surface Vehicles such as Spartan Scout, and Unmanned Aerial Vehicles such as Pioneer.

With the Navy moving to a fleet of shorter-range helicopters based on the various SH-60 variants, the abilities to refuel helicopters and to store and handle heavy mission-specific equipment (such as towed mine-hunting sonars) are the minimum capabilities required for an HSV to serve as a forward lilypad for helicopter operations. The inability of the present surrogate ship to do either, limited the amount of realistic at-sea testing that could be done. A follow-on ship, *HSV-X2*, will be capable of refueling helicopters and allowing them to remain on board for 24 hours. Thus, *HSV-X2* will offer more capability to experiment with concepts involving air support.

Launch and recovery of small boats and autonomous vehicles (surface and sub-surface) in seas up to 5 feet

Finding: Joint Venture *demonstrated the ability to launch and recover small boats and autonomous vehicles in seas up to 5 feet. This capability should be improved to enhance the ship's ability to develop or test tactics and operational concepts. Launch systems and procedures should be developed that allow the launch and recovery of larger vehicles in higher sea states without requiring the HSV to come to a near stop or use a manned support boat in the water. See references [6, 15-18, 20-21, 25, 27].*

The ship's crew launched and recovered small boats and autonomous vehicles from *Joint Venture*, using a single-point-of-support crane at the stern of the ship. Figure 6 shows a typical autonomous vehicle, a BPAUV, suspended over the water during recovery.

Figure 6. Recovery of a BPAUV from *Joint Venture* in calm seas at Panama City, Florida

The launch and recovery procedures developed by the crew were capable of launching and recovering manned (7-meter RHIB, CRRC) and unmanned vehicles in seas up to 3–5 feet. For small manned craft, such as the 7-meter RHIB or CRRC, about 3–5 minutes was required for each launch or recovery. For unmanned vehicles or larger manned vehicles, somewhat more time was required. For example, during Fleet Battle Experiment Juliet, about 10 minutes elapsed from the time the 11-meter RHIB or Seal Delivery Vehicle, SDV, was hooked up on the sling in the water to the time it was at rest on the trailer.

While this speed of delivery/recovery and capability was adequate for *Joint Venture* to serve as a surrogate test bed for a variety of autonomous vehicles, development and demonstration of effective tactics and operations will require a launch and recovery system with greater capabilities. In particular, we should develop a launch and recovery system that allows us to do the following:

- Launch and recover in seas higher than 5 feet: For seas with waves of 3–5 feet, the crew developed procedures (using the lee of the ship and tending lines) that allow the launch of craft up to about the size of an 7-meter RHIB. (See figures 6 and 7.) For small surface craft (manned or unmanned), this might be an acceptable operational constraint. Underwater vehicles (manned or unmanned) could potentially operate in higher sea states, if they could be launched and recovered.
- Launch and recover without requiring *Joint Venture* to come to a near or complete stop: This would allow more realistic testing of tactics seeking to exploit the high speed of the HSV in support of autonomous vehicles.
- Launch and recover larger vehicles in open seas: Launching larger vehicles such as the 11-meter RHIB in open seas is problematic due to the overhead clearance limitation of the stern crane. After a year of experimentation, the crew and SPECWAR personnel developed procedures allowing the launch and recovery of an 11-meter RHIB, but the necessary modifications are only approved for sheltered waters.

Figure 7. Tending lines restraining the crane block during moderate seas

- Recover unmanned vehicles without the aid of a support boat: While *Joint Venture* has developed procedures for launching some varieties of unmanned vehicles without a second boat in the water, recovery still requires the aid of a small RHIB or CRRC to attach the unmanned vehicle to the crane. (See figure 8.)

Achieving these enhancements would appear to require a redesign of the system, since the current procedures seem to be the best ones available for the existing single-point-of-support crane on *Joint Venture*.

Figure 8. Members of a Mobile Diving Salvage Unit prepare to connect an autonomous vehicle to the *Joint Venture*'s stern crane for recovery during JTFEX 02-1

The feasibility of a reconfigurable ship with an integrated C4I suite capability was demonstrated in at-sea testing

A single C4I suite can be reconfigured to support different staffs

Finding: The Joint Operations Center (JOC) on Joint Venture *proved capable of sequentially supporting two different command staffs charged with planning for and controlling tactical operations with minimal time required to switch between roles. See references [15-17, 20-21, 24, and 27].*

During Millennium Challenge/Fleet Battle Experiment Juliet, two different command staffs used *Joint Venture's* JOC to plan for and control tactical operations.

- COMMCMRON 3 embarked 26 through 31 July. During this time, 20 personnel from the MCMRON staff planned and executed MCM operations (e.g., surveillance, Q-route clearance). The C4I suite of the Joint Venture allowed the staff to host its MCM planning tools, command tactical units, and collaborate in real time with upper echelons of command. The C4I suite also provided access to a Common Operational Picture broadcast to all elements of the Joint Task Force by the Joint Task Force Headquarters.

- An NSW Task Unit Command Element of a similar size embarked onboard *Joint Venture* 1 through 5 August. The command element planned for and controlled Visit, Boarding, Search, and Seizure operations while on board. The NSW Task Unit Command Element augmented *Joint Venture's* C4I suite with additional radios to facilitate communication with dedicated surveillance assets.

These successes during Millennium Challenge/Fleet Battle Experiment Juliet were made possible by the maturation of the *Joint Venture's* C4I suite. They demonstrated:

- The feasibility of hosting a 20-person command staff on board a ship the size of *Joint Venture*.
- The capability to switch the C4I suite rapidly (in less than 24 hours) between two different staffs with different C4I system requirements.

The two embarked staffs mentioned ways in which the C4I suite could be improved to enhance the support it provides the embarked staff. Most of these involved requests for more bandwidth or access to special circuits/C4I tools. One suggestion dealt with improving the communication path between the ship's bridge and the JOC. Currently that communication is relayed either by a runner or by a handheld radio.

Reconfiguration in support of multiple warfare areas

Finding: During the experiments, the Navy exercised a number of missions aboard Joint Venture. *The effort required to switch between missions is better described as requiring a change-out of embarked personnel and equipment rather than as swapping modules in the same sense that existing modular combatants (such as the Danish* Flyvefisken*-class ships) swap out modules. Change-outs between various mission loads during experimentation took minimal time. During the various experiments, reconfiguration always took less than a half-day and in most cases required only a few hours. The experiments* *demonstrated the potential for reconfiguration and the ease with which a ship could be reconfigured. However, the desirability of modular combatants is still to be determined, by issues other than the capability to quickly and efficiently reconfigure a ship. These issues are primarily the potential cost savings and the impact of reconfiguration on mission performance. They are best addressed in design studies and not in at-sea experimentation. See references [1, 3, 6, 11-12, 15–18, 20–21, 27].*

Some examples of missions undertaken with special equipment embarked aboard *Joint Venture* are:

- Environmental Survey (NUWC LOE)
  - — Equipment: 48 expendable bathythermograph buoys, hand-held launcher, ruggedized laptop to process data from buoys (transmitted over a wire)
- Environmental Survey (JTFEX 02-1)
  - — Equipment: Klein 5000 multi-beam side-scan sonar
- Shallow-water mine identification (MIW LOE2, JTFEX 02-1)
  - — Equipment: Dive boat (7-m RIB) and trailer, diving rigs, communications devices, Remote Exploratory Mine Underwater System (for JTFEX 02-1 only)
- Mining (MIW LOE 2, JTFEX 02-1, Strong Resolve)
  - — Equipment: Mine shapes or exercise mines ranging in number from 6 to 40
- Support for autonomous vehicle operations (MIW LOE 2, JTFEX 02-1)
  - — Equipment for MIW LOE 2: 2 BPAUV (10 ft long, 486 lb dry) on trailers, connex van with maintenance, programming and processing equipment, support boat (7-m RIB)
  - — Equipment for JTFEX 02-1: Owl Mk III unmanned surface vehicle, Spartan Scout unmanned surface vehicle, Roboski unmanned surface vehicle, communications equipment and controllers for USVs, support boat (7-m RIB)

- Mine warfare command and control (MIW LOE 2, JTFEX 02)
  - — Locker of office supplies, several spare laptops, special MCM decision support software
- Naval Special Warfare
  - — Specialized communication equipment for command element, mobility vehicles (CRRC, RHIB, SDV), small arms lockers

These examples are typical but not exhaustive. Loading of specialized equipment did not limit usage of the ship to a single mission. For example, during Millennium Challenge, *Joint Venture* supported a ship-to-objective-maneuver (STOM) event while COMCMRON 3 was embarked and controlling MCM operations.

All of the diverse systems imposed relatively modest footprint demands on *Joint Venture*. Installation and use of these systems aboard *Joint Venture* generally differed little from what would have been done aboard other ships. By way of contrast, one NWDC concept paper [3] envisions pre-packaged modules that roll on and off the ship, quickly mate with the ship's services, and allow the ship to be configured for a wide array of missions.

Sample modules from references [1 and 3] are:

- Berthing trailers (10 berths per trailer)
- Sanitary trailers
- Operating rooms
- Medical laboratory
- Hospital bed trailers
- Mammal pool
- Water trailers
- Food trailers.

One can imagine other containerized kits such as a RHIB maintenance bench, dive support kit, and maintenance shop for MCM equipment. Since none of these modules exist, experiments to date have used as surrogates existing equipment brought on board for brief stays.

The closest example to the NWDC modular concept is provided by operations of an underwater autonomous vehicle, the BPAUV, during MIW LOE 2. For BPAUV support, a small container loaded on the vehicle deck and attached to ship's power provided pre-mission programming, post-mission processing, and maintenance support in a single package. While the BPAUV also conducted operations off of USS *Sentry*, a surface MCM ship, the support container was not moved onboard that ship. During the MIW LOE, the BPAUV suffered a casualty during a dive and required repairs that were made using the spare BPAUV and equipment in the support container embarked on board *Joint Venture*. This container was not embarked on USS *Sentry*, and that ship would not have had a similar capability to repair the vehicle.

While testing to date has demonstrated that the open spaces of the vehicle deck can be used for a variety of different purposes, it has not addressed important issues related to the modular concept such as:

- If multiple modules are purchased for a fleet of general purpose HSVs to enable them to participate in a variety of missions, how would the cost of the fleet plus modules compare to a similar fleet of ships in which each ship is designed to support a more limited array of missions while still providing coverage across all the mission areas?
- How will the Navy manage the modules to ensure that it gets to the right HSV at the right time?
- What is an acceptable time to swap modules on and off?
- What are the trade-offs between loading multiple modules to allow multiple missions and the overall endurance (range, time on-station, etc.) of the ship?

Many of these issues are best examined in wargames and studies.

In addition, many of the modular approaches given in references [1 and 3] assume robust interfaces between the ship and the outside world. Examples are:

- Ability to embark helicopters
- Launch and recovery of small boats and vehicles with an in-deck moon pool
- Ability to work with a sea-base, and conduct vertical and underway replenishment
- Efficient movement of cargo of all descriptions on and off the vehicle deck
- Efficient mating of modules with the base ship.

Recommendations

The at-sea testing with *Joint Venture* and experience with *WESTPAC Express* have shown that the ship's speed can be exploited for movement and precise high-speed delivery of expendable sensors and mines. The operations of *WESTPAC Express* have also shown that the larger commercial high-speed ferries provide an attractive alternative to airlift for administrative movements of forces together with their equipment within a theater.

While these accomplishments are real, more remains to be done in evaluating the potential utility of an HSV for military purposes. Current at-sea experiments are constrained by the commercial requirements for which the ship was originally conceived, designed, and built. To make further progress in understanding the degree to which we can exploit this commercial technology, we recommend:

- Integration of future experiments with the Littoral Combat Ship study options
- An engineering study of the interface requirements
- Analysis of the modular concept.

Integration with Littoral Combat Ship study

The Littoral Combat Ship (LCS) study being undertaken by N76 is charged with investigating LCS options with an emphasis on developing reconfigurable modules and packages. There are aspects of the modular concept that should be analyzed independent of the missions supported by the modules, and we make recommendations for this area below.

Given that a mission area and potential modules have been identified, experimentation with an HSV could help refine and test the concepts for employment of the LCS and its mission modules. This is particularly true for those concepts where the LCS relies heavily on helicopters and autonomous vehicles to accomplish missions such as undersea warfare (anti-submarine and anti-mine) and surface warfare against small boats. Future experimentation should be integrated with the LCS study so that the concepts tested at sea are those being considered by the study team for future ships.

Engineering study of interface requirements

Experimentation with *Joint Venture* reinforced the importance of a ship's interfaces with the outside world. In cases where the interface was well developed or the interface requirements were minimal, *Joint Venture* acted as an excellent surrogate for testing the potential utility of future ship designs. Examples include movement of rolling stock on and off the vehicle deck and mining. However *Joint Venture* proved to be more limited as a surrogate where the interface was either lacking (movement of cargo from ship-to-ship at sea) or limited (aviation support).

In order to develop refined estimates of the potential military utility of a small HSV, we need to understand which interfaces are feasible within the constraints of the ship's design and which are not. At present, our understanding is poor, particularly concerning interfaces which have a high ship impact such as the long-term embarkation of helicopters. Accordingly, we recommend engineering studies to estimate the feasibility of providing:

- Aviation support for long-term embarkation of one or more helicopters[7]
- Transfer of cargo at sea to support sea-basing concepts
- More efficient launch and recovery of small boats, unmanned undersea vehicles, and unmanned surface vehicles
- More efficient loading and unloading of cargo and the ability to mate with a wide variety of piers/causeways
- Efficient mating of modules to the base ship.

Analysis of the modular concept

To estimate the potential utility and practicality of the modular concept, we will have to determine that modular ships can "fit in" with operations by a forward-deployed Navy. For example, consider that an HSV of the future is forward-deployed to the Persian Gulf and is configured for (and providing) intra-theater lift. If we want the ship to quickly shift to a mine countermeasure support role, we must quickly put the required modules and staff augmentation on the ship. This raises a host of operational questions:

- Where do we store the modules? In theater or in CONUS?
- What port support do we need to install the modules? Or would we attempt to install them from a sea-base?
- Where does the augmentation staff come from? How does it marry up with the ship? How does it train in advance on the modules?

7. As written, this recommendation refers to manned aircraft. An alternative concept would be to have the ship provide similar services for unmanned aircraft. This will only become of interest when suitable unmanned aircraft capable of landing and taking off from a small flight deck become available. The follow-on ship, HSV-X2, will be capable of allowing helicopters to embark overnight, re-arm and refuel. This will allow direct testing of "lilypad" concepts and reduce the artificialities involved in experiments exploring the utility of providing more robust aviation support.

- If the ship is required to deploy to a different theater as part of a crisis response, do the answers to the above questions change?

At-sea tests with the current or future test-bed ships are not likely to shed much light on these issues. A more fruitful approach would be to use one or more wargames to identify the issues and develop straw-man concepts of operation for implementing a modular ship concept. The concepts of operation should then be examined in representative scenarios by operations analysis. In practice, this would probably raise more issues, which might be best addressed by further wargaming to refine the concepts of operation. The end result would be a developed set of conditions under which modular ships were expected to be both useful and cost-effective.

At the conclusion of the wargaming and analysis, we would be in a position to develop hands-on experiments to validate critical parts of the modular concept. (These experiments might or might not require the services of a ship if we are focussed primarily on handling of the modules themselves.)

Specific lessons learned that deal with the suitability of the *Joint Venture* design for military operations

Here we address *Joint Venture*'s overall suitability for naval operations. These findings should be taken as describing the capabilities of the test-bed ship, and are not true of all potential HSV designs. The goal of this section is to inform the design of HSVs for future military applications.

Lessons learned from at-sea tests

Joint Venture's seakeeping was unrestricted in seas up to 8 feet

Finding: In a fully loaded condition, operations by Joint Venture *were unaffected in seas up to a significant wave height*[8] *of approximately 8 feet. In higher seas, significant amounts of slamming occurred when* Joint Venture *headed into the waves at speeds in excess of 10-15 knots. The speed at which the high-speed slamming regime began depended upon the wave period and loading of the ship. The slamming produced a rough ride (described by ship-riders as similar to an aircraft in turbulence) and in some instances induced structural damage. This places constraints on, but does not eliminate, operations by* Joint Venture *in seas between the 8-foot wave height where slamming starts and the 16-foot wave height limit imposed by the classification society. It is possible that a redesign of the ship could either mitigate the impact of slamming or produce a larger regime of unrestricted operations. See references [4–7, 10, 19, 21, 23, 25–27].*

8. Significant wave height is defined as the height reached by 30 percent or more of the waves.

Table 5 shows estimates of *Joint Venture*'s maximum speed when the ship is fully loaded as a function of significant wave height and direction of the seas. Entries in the table reflect estimates made by the Officer in Charge of *Joint Venture* and the manufacturer. (The manufacturer's estimates are in parentheses.) There is fair agreement between the two estimates, and the bottom line is that for significant wave heights in excess of 8 feet, speed should be curtailed to prevent slamming whenever the intended course is not very broad on the beam.[9] The estimated maximum speeds in table 5 are significantly lower than the "absolute" safety limits imposed by the classification society for high-speed ferries. The limits imposed by the classification society imply that the ship could head into 12+ foot seas at 30 knots. Practice indicates that *Joint Venture* would experience many slamming events under those circumstances.

Table 5. Estimated maximum speed[a] of *Joint Venture* vs. significant wave height

	Max. speed (knots) at Significant wave height[b]		
Sea direction	8 ft	10 ft	15 ft [c]
Head	39 (39)	15 (15)	10 (15)
Broad bow (45 degrees +)	39 (39)	39 (39)	15 (25)
Beam	39 (39)	39 (39)	25 (30)
Quarter	39 (39)	39 (39)	25 (35)
Stern	39 (39)	39 (39)	32 (35)

a. For the ship fully loaded with fuel and cargo. In a light-ship configuration the maximum speed for waves of 8 ft or less is higher. The maximum speed observed by *Joint Venture* during trials was about 45.2 knots.

b. Estimates in parentheses are those of the manufacturer; other estimates by the OIC of *Joint Venture*.

c. The commercial classification society does not certify *Joint Venture* for operations in seas in excess of 5 meters (16.4 feet). After the evaluation period of this report, *Joint Venture* transited the Mediterranean Sea for two days at 32-35 knots in following seas of up to 15 feet.

9. Reference [5] comes to a similar conclusion.

We should point out that the table is based on experience in operating *Joint Venture* under a fairly limited range of conditions:

- The ship was fully loaded. In particular, the long-range fuel tanks were full. Since fully loading the long-range tanks depresses the bow, the onset of slamming might be delayed if the ship were operating with fuel in the day tanks only.
- The period between the waves was short, reflecting operations in coastal waters. In a deep-water environment, a longer period between the waves might reduce the intensity of the slamming and delay its onset.

The 10 January 2002, transit of *Joint Venture* south from Little Creek, VA, to Morehead City, NC, is typical of the operations that induced slamming.

For this trip, *Joint Venture*'s day and long-range fuel tanks were filled, but it had no cargo on the deck. Both the crew and the instruments measured waves of 8–10 feet in height with a very short period of 6 seconds. Wavelength was 180 feet, roughly half that of a deepwater ocean basin.

When heading into the waves, there was a great deal of slamming on the center bow and aft wet decks. During the worst portions of the transit, 100–120 slams per hour occurred. Through experimentation, the crew determined that placing the seas 45–60 degrees off the bow was required in order to reduce the incident of slamming significantly for speeds in excess of 20 knots. At the suggestion of the manufacturer's representative, the crew attempted to "punch through" the swells at high (32+ knot) speed. This reduced the number of slams slightly but made the eventual slams much more severe.

During periods of intense slamming, about 25 percent of the embarked personnel had symptoms of sea-sickness. Because the ship's motion was so unpredictable and turbulent, embarked personnel had trouble acclimating to it. Since the pilot house is roughly above the center of gravity, its occupants had a somewhat smoother ride and less sea-sickness than those occupying some of the other ship spaces. Other than slamming, normal ship motions such as roll and pitch were acceptable in the 8- to 10-foot seas and were not an issue.

Upon arrival in Morehead City, a structural inspection identified some damage in the bow sections of the ship. A transverse bulkhead was compressed and distortions in the bulkhead plate visible. A frame flange weld cracked and parted, and the frame plating beneath the frame flange cracked and tore. A number of other cracks and deformations in the primary structure were found in the interior bow region. Repair (which involved aluminum welding) was not time consuming. A single welder repaired all the damage in a few days.

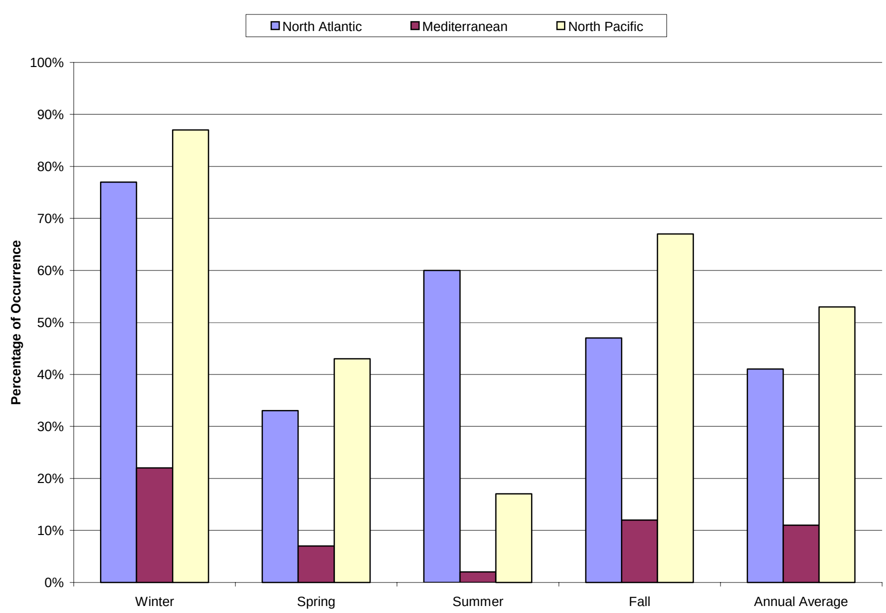
The experience of the transit to Morehead City was corroborated with later operations in the North Atlantic, Norwegian coastal waters, and the Baltic. This experience indicates that, at least for this ship design, operations in the regime where slamming starts should be minimized as much as possible. This places constraints on, but does not eliminate, operations by *Joint Venture* in seas between the 8-foot wave height where slamming starts and the 16-foot wave height limit imposed by the classification society. Through a combination of tacking to avoid head-on seas, slowing down, and varying departure times, the effects of weather can be managed. For example, during a recent transit from Larvik, Norway, to Rota, Spain, *Joint Venture* left port early and adjusted its track to allow a high-speed transit through 10-foot seas ahead of much worse weather that would have forced the ship to remain in harbor. While the adjusted track was several hundred nautical miles longer than the direct course, the ship's speed and its early departure to avoid the worst of the weather allowed it to arrive in Rota ahead of schedule. In comments on this report, the Navy OIC stressed the value of high speed in maneuvering to avoid bad weather. During all open-ocean transits he used that speed to either avoid storms or travel in lulls between storm systems.

WESTPAC Express has similar weather restrictions. It can operate in seas with a significant wave height up to 16 feet; its operations are impacted when heading into waves of 9 feet or higher. On a recent mission from Yokohama to Okinawa, *WESTPAC Express* slowed its speed from 30 knots to 22 knots when it encountered seas with a significant wave height of about 12 feet and began looking for sheltered waters to ride out the storm. On the same voyage, it also sustained damage to its bow ramp and several tiedowns on the vehicle deck were pulled out. Notwithstanding the sensitivity to weather, *WESTPAC*

Express still managed to fulfill its Fiscal Year 2002 operations schedule of administrative movements satisfactorily.

How common are the kinds of seas that would impact the operations of *Joint Venture* or *WESTPAC Express*? The short answer is that they are not uncommon, particularly in the middle of large ocean basins. To illustrate, figure 9 shows the frequency at which waves greater than 8 feet are present in the North Atlantic Ocean, Mediterranean Sea, and North Pacific Ocean. This is an approximate measure of the amount of time that wave conditions would constrain operations since it does not take into account ship loading or the period between wave crests. Since the ship would not necessarily be heading into the waves, ship operations would not be precluded as often as the histogram might suggest.

Figure 9. Percentage of times that waves greater than 8 feet can be expected[a]



a. Sources of data:
(1) NAVAIR 50-1C-538, *US Navy Hindcast Spectral Ocean Wave Model Climatic Atlas: North Atlantic Ocean,* NAVOCEANO, October 1983; location chosen is centered on 40N 40W (same latitude as New York City).
(2)NAVAIR 50-1C-557, *US Navy Hindcast Spectral Ocean Wave Model Climatic Atlas: Mediterranean Sea,* NAVOCEANO January 1990; location chosen is centered on 35N 20E.
(3)NAVAIR 50-1C-539, *US Navy Hindcast Spectral Ocean Wave Model Climatic Atlas: North Pacific Ocean*, NAVOCEANO, March 1985; location chosen is centered on 40N 180E.

Informal discussions with the HSV sea-keeping/structural analysis team at Naval Surface Weapon Center, Carderock Division, indicate that a number of design changes might be investigated to either delay the onset of slamming or mitigate its impact. These include:

- Distributing the fuel storage more evenly throughout the demi-hulls and making provisions to pump fuel from tank to tank, to allow greater control of ship trim
- Increasing the size of the ship to raise the bow and aft wet decks higher off the water
- Modifications to the wave-piercing catamaran design, including:
  - Extending the demi-hulls further forward of the bow hull to help keep the bow "up" in high seas
  - Changing the shape of the bow hull
- Using a hull design other than that of a wave-piercing catamaran.

It should be emphasized that these are suggestions for investigation. Some of them might not prove to have significant benefits or might introduce other limitations.

How does the seakeeping ability of the Joint Venture compare with that of other Navy combatants? All of the Navy's ships are forced to reduce speed in high seas to minimize injuries to personnel and damage to systems such as hull-mounted sonars. Smaller ships suffer more restrictions than larger ships. For comparison purposes, table 6 shows maximum speed as a function of wave-height for a Cyclone-class coastal patrol ship.

The weather restrictions for the Cyclone-class ship are similar to those for *Joint Venture*. In high enough seas, the performance of both ship types is degraded.

In summary, *Joint Venture,* like all ships, has some operational limitations. While the operational limitations of the particular wave-piercing catamaran design used for *Joint Venture* do not appear to disqualify

Table 6. Structural operating limits for Cyclone-class coastal patrol ships[a]

Significant wave height (feet)	Maximum speed (knots)
Up to 4	35
6	30
8	24
10	16
12	9

a. Reference NTTP 3-05.32, *Patrol Coastal Class Tactical Manual*. Limits quoted for heading into the seaway.

an HSV of that hull type for Navy service, further study into alternative hull forms and different wave-piercing catamaran designs could maximize the set of conditions under which the ship can conduct operations unconstrained by seakeeping considerations.

Joint Venture can access austere ports efficiently

Finding: Joint Venture *demonstrated the ability to support the tactical movement of units up to the size of two companies.* Joint Venture *delivered company-sized units intact into ports with depths as shallow as 18 feet with restricted maneuvering room, and quickly discharged the units without the aid of local pilots. See references [7, 23, 25–26].*

The ability of *Joint Venture* to move up to two companies of personnel together with equipment was used during both Battle Griffin [23] and Millennium Challenge [7, 25–26] to maneuver ground units tactically. An event during phase 5 of Battle Griffin shows the potential. *Joint Venture* picked up a ground element with 108 Marines and 24 tactical vehicles (138 short tons of payload) in a commercial port and delivered them to an austere port to reinforce MAGTF forces ashore. Final delivery of the Marines ashore was rapid and efficient. *Joint Venture* approached the pier unassisted by local pilots, dropped and secured the stern quartering ramp, off-loaded the Marines with their vehicles, and departed the pier within 15 minutes of the time it first started securing to the pier.

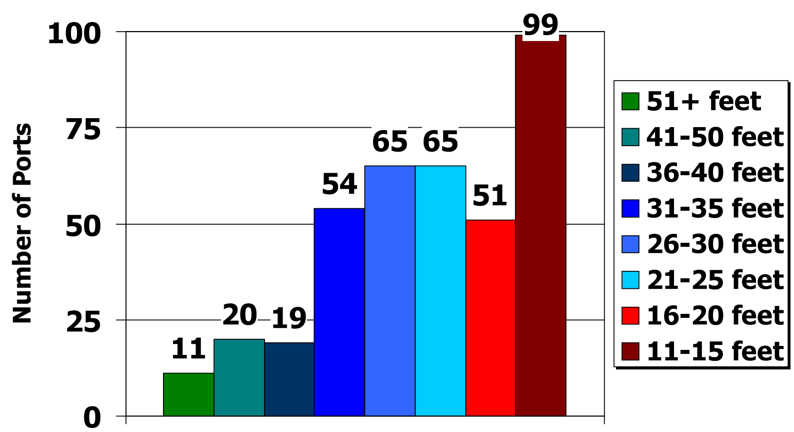
During Millennium Challenge, *Joint Venture* approached an improvised pier[10] (made up of causeway sections in the Del Mar Boat Basin—see figure 10) in a restricted channel with the water depth as shallow as 18 feet. It delivered four LAVs, three LVSs (one with a 20-foot ISO container, one with three pallet containers and one with three QUADCON containers), and two 5-ton trucks, to the forces ashore. Following this resupply event, the ship embarked noncombatant evacuees and departed. Total time spent by *Joint Venture* inside the harbor was approximately 1 hour (including the channel transit into and out of the basin).

Figure 10. *Joint Venture* docking at an improvised pier in Del Mar Boat Basin made up of causeway sections. Pier extended about 100 feet from shore.

10. Building an "expeditionary" pier and demonstrating the interoperability of Joint Venture with the pier was a deliberate part of the experiment and does not imply that the existing piers were inadequate.

These two evolutions highlighted the maneuverability of the HSV in getting into a shallow austere harbor with restricted channels and the ship's ability to quickly disembark/embark ground units and other passengers. As we documented in two CNA studies of port depth [29, 30], many more ports are available to a ship with *Joint Venture's* draft (13 feet) than to current large sealift ships and prepositioning ships. Figure 11 (taken from [29]) shows the distribution of ports in the Mediterranean and Black seas. All ports with a depth of 15 feet or greater would be accessible to *Joint Venture* (as would some of the ports with depths of 11–15 feet on a case-by-case basis). Current large sealift and prepositioning ships are limited to the ports with depths of 36 feet or greater.

Figure 11. Distribution of port depths in the Mediterranean and Black seas



Maximum demonstrated endurance on-station of 1 week

Finding: Joint Venture *demonstrated the ability to conduct periodic operations at sea for periods of up to 1 week. Factors limiting the endurance of the test-bed ship include the ship's small crew size, a requirement to visit port to take on fuel or supplies, and maintenance requirements. See references [6, 22–25, 27].*

In the experiments conducted to date, *Joint Venture* typically returned to port every night or at most after staying out 2–3 nights. The principal factors driving this operating pattern include the large numbers of ship riders, which often exceeded the ship's rated berthing capacity (45 berths in dedicated berthing compartments for permanent party and 48 overflow berths), and the requirement to swap systems on/off the ship for testing. The in- and out-of-port routine also provided relief for the ship's crew.

During Strong Resolve 02, NWDC assessed that *Joint Venture* did not have sufficient manning to conduct round-the-clock NATO operations (which in Strong Resolve included a mixture of mining, ASUW, and other missions) without augmentation.

The inter-theater transits provide a better picture of *Joint Venture*'s true endurance. The transit from Moorhead City, North Carolina, to Rota, Spain, is typical. During that transit, 31 crew members and 16 observers/analysts embarked and *Joint Venture* stayed at sea for 144 continuous hours operating at an average speed of 27 knots. While the ship still had some fuel reserves, continued operations would have mandated a return to port within a day. The demonstrated endurance of the ship is consistent with the estimate made by *Joint Venture*'s Officer in Charge during the Fleet Battle Experiment After-Action Review that with the current ship, 2 weeks would be the maximum endurance at sea. This assumes that the ship could take on fuel every 5 days or so.

Crew size of 31 is too small to support sustained operational missions

Finding: When operating under Navy Administrative Control, Joint Venture *was crewed by 31 personnel—4 Navy officers, 18 Navy enlisted, 3 Army warrant officers, 3 Army enlisted, 2 enlisted provided by NAVSPECWARCOM, and 1 Marine enlisted. That crew size sometimes proved to be inadequate for routine requirements such as manning all force protection positions when in port. It also proved to be less than optimal for supporting the intense operating pace prevalent during most of the experiments. See references [6, 24, 25, 27].*

One attraction of small HSVs is the potential to perform missions with crews that are much smaller than those manning current ships such as destroyers or even frigates. Determining the optimum mix of permanent crew and augmentation as part of mission configuration is an area that requires further study. For the Army Theater Support Vessel Concept, the envisioned crew size is identical to that of *Joint Venture,* 31 personnel. For Navy concepts focused on war-fighting missions vice intra-theater lift, the experiences with *Joint Venture* suggest that additional personnel may be required in the form of either augmentees accompanying the war-fighting modules or additional ship's company.

As currently staffed, *Joint Venture* found itself unable to meet routine Anti-Terrorism/Force Protection measures while in home port without support from the port. When operating forward, augmentation with a security detachment (either carried onboard or attached to the port of call) was required to meet Combatant Commander force protection requirements. Since the HSV concept envisions operations in and out of ports with minimal military infrastructure, augmentation with a security detachment may be required to support those visits.

During the experiments, the ship's company is responsible for supporting mission evolutions such as flight quarters and small boat operations in addition to their watchstanding duties. In times of intense activity, this puts a lot of stress on the ship's crew. During Fleet Battle Experiment Juliet four male petty officers volunteered to wear sleep-measuring devices over the 13 days of the exercise. The devices recorded that these four individuals averaged about 3 hours of sleep per night over the 13-day period.[11] This is far below the amount of sleep required by humans to function for a sustained period of time.

The ship's Officer in Charge estimates that the total crew size should increase to 40, to enable (among other things) the ship to operate in a three-section watch while underway and allow some key personnel

11. Information from draft Naval Postgraduate School report on Millennium Challenge 02.

to be pulled out of the watch rotation to support mission-related evolutions such as flight quarters or small boat operations.

Recommendations

The initial testing with *Joint Venture* provided valuable insights into the seakeeping and other characteristics of this particular wave-piercing catamaran design. More work remains to be done, and much of the structural response data that have been collected will require additional analysis to digest.

Based on the results to date, the following issues seem to be worthy of attention as the military seeks to determine how practical HSVs are for military purposes.

- Alternative designs to improve seakeeping: While the results so far indicate that the wave-piercing catamaran design has reasonable seakeeping, the limitations on heading into seas with a significant wave height greater than 8 feet suggest that alternatives should be investigated.
- Ship signature: The acoustic and magnetic signature of *Joint Venture* was measured using the Virtual Exercise Mine System (VEMS). The resulting measurements are of low fidelity, and improved measurements will eventually be required to adequately model the ship's susceptibility to mines. Radar and pressure signatures are also required for vulnerability modeling.
- Ship vulnerability: An engineering analysis of the vulnerability of the HSV to various types of munitions would set the security environment required for operations by the HSV.

- Ship durability: The Navy must assess the expected service life of the ship design under various operating conditions—5 years, 10 years, or 25 years. It must also determine the expected level of maintenance for repairs to the structure and propulsion systems.

- Ship's manning: The small crew size of *Joint Venture* is an important component in keeping its costs lower than those of current Navy ships. But experiments have shown that the a crew of the current size cannot maintain round-the-clock operations or handle extra tasks such as in-port security without augmentation. The Navy must decide on the operating envelope for potential HSVs, then ask, "How much manning is required?" and "Under what conditions will augmentation be the preferred method of handling a short-lived requirement?" An important input to these questions will be the missions the ship is expected to perform. This is another reason for future experimentation to work closely with the study of Littoral Combat Ship options.

Resolving these issues will involve making detailed measurements of *Joint Venture* and other test-bed platforms, then combining them with engineering studies of alternative designs. The at-sea tests will be valuable in providing benchmarks and validating design assumptions.

Appendix: the test-bed ship

Table 6 shows some of the salient statistics of *Joint Venture*, a wave-piercing catamaran. The ship uses water-jets for propulsion powered by four 7200-kW diesel engines. It is constructed out of aluminum to minimize its overall weight.

INCAT Tasmania Pty. Ltd. designed and built *Joint Venture* as a high-speed car ferry. It spent the first two years of its life as an operational car ferry in New Zealand before being replaced by a larger ship of the same type.

Table 7. *Joint Venture* HSV-X1 statistics

Item	Value
Length	96 meters
Beam	27 meters
Draft	3.6 meters
Top speed	38 knots (fully loaded, operational)
	45 knots (light ship)
Total deadweight	745 long tons (cargo capacity is deadweight less fuel)
Fuel capacity	150 long tons in day tanks
	325 long tons in long-range tanks
Maximum range	1,000 n.mi., fully loaded, 35 knots, day tanks only
	3,000 n.mi. fully loaded, 35 knots, all tanks full
Berthing	45 personnel in dedicated berthing compartments, 48 transient berths
Seating	363 persons[a]

a. This is the "as-delivered" seating capacity. At present some number of seats (roughly 75) have been removed to make room for additional planning spaces.

The next three figures show diagrams of *Joint Venture* and help us discuss the modifications made to the ship to support experimentation. Figure 12 is a top-view of the ship. The helicopter deck (25 meters by 20 meters) on top has been certified for daytime VFR takeoffs and landings of SH-60, and CH-46 series helicopters. No provision exists to refuel aircraft, and any items taken on/off the helicopters must be carried by personnel to and from the flight deck using the ship's passageways. This level also has a sky lounge with a seating capacity of 40 (shown in green), typically used for briefings and entertaining distinguished visitors. The pilot-house is on top of the ship above the green area, and has an automated navigation system using electronic charts.

Figure 12. *Joint Venture* HSV-X1, top view (not to scale)

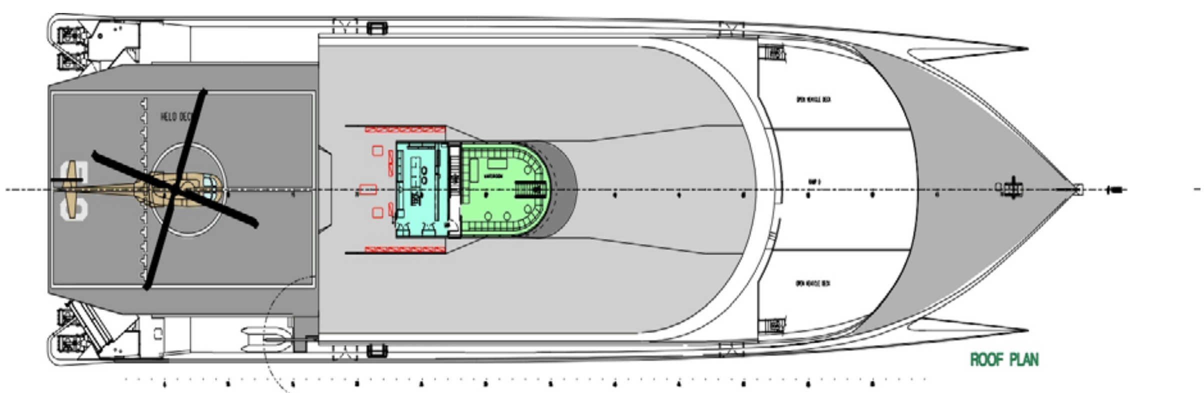
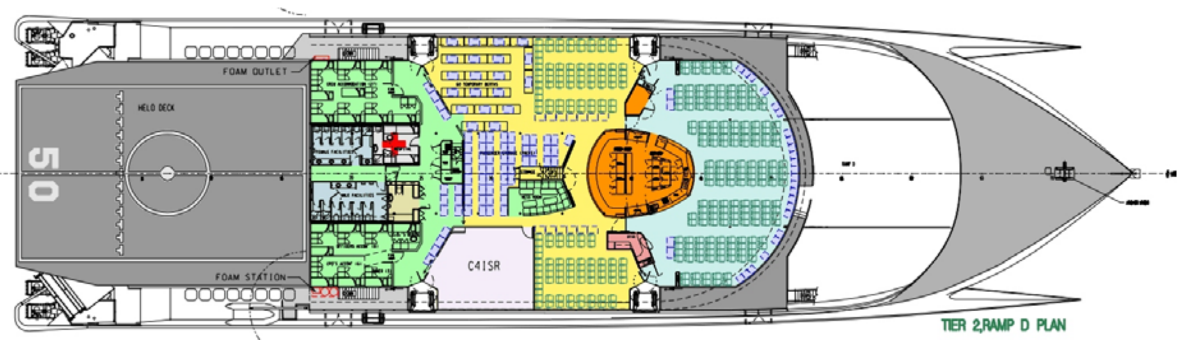


Figure 13 shows the main passenger deck. Originally this area contained sanitation facilities, seating for passengers, and a snack bar. Modifications for experimentation include the addition of berthing compartments for 45 (the area in green), an overflow compartment with transient berthing for 48 (the space immediately forward of the permanent berthing on the port side of the ship), and a 700-sq-ft space configured as the Joint Operations Center (JOC, labeled C4ISR in the diagram) with installed radio circuits and workstations in the corresponding location on the starboard side of the ship. In addition to the features shown on the diagram, the seating in the space just forward of the JOC has been removed to make room for a planning space of about 700 square feet.

The C4I space is intended to support a small command staff of about 20 personnel. It has seats for six operators and three technicians.

Figure 13. *Joint Venture* HSV-X1 passenger deck

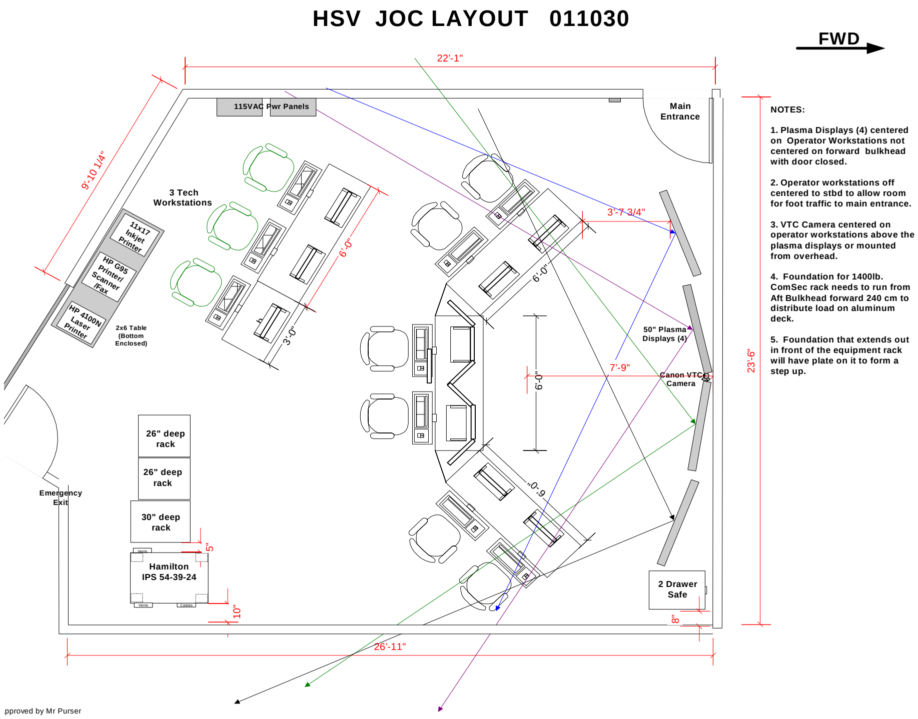


Each operator can view up to three desktop-size screens at his/her console. The wall facing the operators has four screens that can be programmed to show any display available in the JOC. The JOC has connectivity to six circuits (one each HF-secure, one HF-non-secure, one SATCOM, one UHF-secure, one VHF-secure, and one VHF-non-secure), and telephones. The space is intended to provide both NIPRNET and SIPRNET connectivity on a wide-area network (WAN) to enable reachback to shore-based data-bases, email, and message traffic. The battle management software in the JOC is GCCS-M. In addition, other programs such as MEDAL and LAWS are available for specific applications. Figure 14 is a diagram of the current JOC configuration.

Note that in contrast to current Navy ships, nearly the entire passenger deck is one large open space. Since all buoyancy is in the demi hulls, water-tight doors would be redundant on this deck. This design is also influenced by the commercial code for high-speed ferries, which requires that the crew be able to see the entire passenger seating area.

Figure 15 shows the vehicle deck with a notional loadout of 17 light attack vehicles and two HMMWVs. The cargo capacity (in long tons) is given in table 6. Throughout the vehicle deck, clearances vary between 4.6 and 2.0 meters. The overall capacity of the deck is 1,008 square meters. Vehicles usually access the deck through a stern quartering ramp with a rated load capacity of 9 tons per axle (by way of comparison, the

Figure 14. The Joint Operations Center on *Joint Venture* HSV-X1

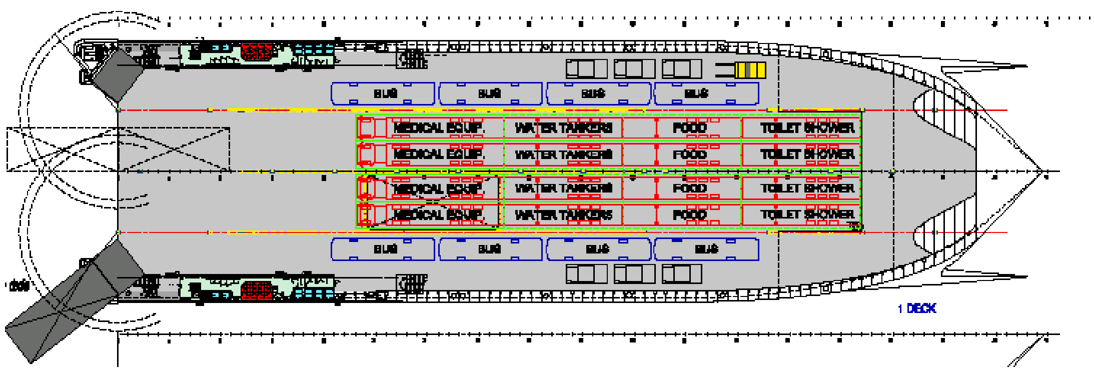


maximum axle load limit allowed on U.S. highways is 19 tons per axle). Not shown on the diagram is a single-point transverse crane at the stern of the ship. This crane is used in launching/recovering small boats and unmanned vehicles.

In addition to carrying cargo, the vehicle deck is also intended to host roll-on/roll-off modules that expand the capabilities of the ship. Figure 16 shows a notional loadout for an HSV configured to serve as a medical support facility or an ambulance to transport patients requiring constant care to other echelons of medical care. The modules shown include operating room and laboratories. Other modules are possible, such as those to support mine counter-measures or special operations.

Figure 15. The vehicle deck on *Joint Venture* HSV-X1

Figure 16. Conceptual HSV configured for medical support



References

This section lists all of the citable references used in the preparation of this report. The experiment quicklooks, reports, etc., are organized roughly by order of the date of the experiment. Most of the references are available from the NWDC SIPRNET site at *www.nwdc.navy.smil.mil.* We also used information obtained from briefings, working papers, emails, and discussions with the experiment partners and ship's crew in the preparation of this report.

General/Concepts and plans

1. Navy Warfare Development Command Concept Paper, *High Speed Vessel (HSV): Adaptability, Modularity and Flexibility for the Joint Force,* Undated

2. INCAT/Bollinger USA, *Joint Venture HSV-X1,* undated

3. Navy Warfare Development Command Briefing, *Transforming the Fleet, HSV Employment Concept,* undated

4. Naval Surface Warfare Center, Carderock Division, *Instrumentation Plan for Seakeeping and Structural Performance Monitoring of the USNS Joint Venture (HSV-X1),* by Thomas Brady et al., December 2001

Trials, experiments, and exercises

5. Naval Surface Warfare Center, Carderock Division, *HSV Performance Trials Seakeeping and Structural Loads: Sea Trials on INCAT Hulls 050 and 046,* by Martin Dipper et al., April 2002

6. Joint Venture, HSV-X1, *Joint Venture (HSV-X1) Lessons Learned 11 Sep - 20 Mar 02,* August 2002

7. Marine Corps Warfighting Laboratory, 5000 CSS TECH/sgb, *High Speed Vessel (HSV) Interim Experimentation Report: Period of 18 October 2001 - 17 March 2002,* May 21, 2002

HSV Static Loading Experiments, 18 and 25 October 2001

8. ONR EXLOG, *HSV-X1 Quick Look Report, Limited Objective Experiments conducted pierside at Little Creek Amphibious Base, Norfolk, VA on 18 and 25 October 2001 respectively,* by J. D. Rice, October 2001

HSV Seakeeping and Structural Load Trials and Flight Certification, 30-31 October 2001

9. Naval message 171002Z DEC 01 COMNAVAIRSYSCOM PATUXENT RIVER MD, *Dynamic Interface Testing Aboard Joint Venture (HSV-X1) First Interim Report*

10. Naval Surface Warfare Center, Carderock Division, *HSV Seakeeping and Structural Load Trials, Offshore Wallops Island VA, October 30-31, 2001,* by M. Dipper et al., December 17, 2001

NUWC Limited Objective Experiment, 7-8 November 2001

11. NNUWCDIVNPT HSV-X1 LOE 01-1, *High Speed Vessel (HSV-X1) Joint Venture, Quicklook Report,* by C. Julius, December 2001

SOF Interoperability LOE, 13-16 November 2001

12. Naval Message, 201659Z NOV 01 COMSPECBOATRON TWO, *HSV and Skjold quicklook for SOF interoperability 13-16 Nov*

USMC Load-out experiments, 27-30 November 2001

13. ONR EXLOG, *HSV-X1 Quick Look Report, Limited Objective Experiments (LOE) conducted during the period of 27 Nov-30 Nov 2001,* by J.D. Rice, December 2001

14. Marine Corps Warfighting Laboratory 3000 CSS TECH/jbs, *Joint Venture Limited Objective Experiment (LOE): Quick Look Report,* by J. B. Stone, IV, Capt., USMC, 11 December 2001

Mine Warfare Limited Objective Experiment, 2-6 December 2001

15. Naval Message, 112009Z DEC 01 COMNAVWARDEVCOM NEWPORT RI, *High Speed Vessel Joint Venture (HSV-X1) participation in MIW Limited Objective Experiment Number 2 (MIW LOE 2) - Quicklook Report*

16. Navy Warfare Development Command, *High Speed Vessel Employment in Mine Countermeasures Role: USS Joint Venture in MIW Limited Objective Experiment #2, November 31-December 9 2001,* by S.P. Gallup, January 31, 2002

17. CNA Research Memorandum D0005629.A2/Final, *Analysis of HSV Issues for Mine Warfare Limited Objective Experiment Two,* by B. Reed et al., February 2002

18. Naval Surface Warfare Center Dahlgren Division, Coastal Systems Station, *Joint Venture HSV-X1 MIW Interoperability Demonstration Report,* December 2001

Bulk Fuel Company, 2nd Engineer Support Battalion LOE, 10-11 January 2002

19. Marine Corps Warfighting Laboratory, *Bulk Fuel Company, 2nd Engineer Support Battalion LOE, Quicklook Report,* by Capt. J. Stone et al., January 2002

JTFEX 02-1, 14-16 January 2002

20. Naval Message, 011142Z FEB 02 COMNAVWARDEVCOM NEWPORT RI, *JTFEX 02-1 Limited Objective Experiment (JTFEX 02-1 LOE) Quicklook Report*

21. Navy Warfare Development Command Maritime Battle Center, *JTFEX 02-1 Final Analysis Report,* May 2002

Battle Griffin and Strong Resolve, 4 February - 15 March 2002

22. Naval message, 291719Z MAR 02 COMNAVWARDEVCOM NEWPORT RI, *Joint Venture (HSV-X1) Exercise Strong Resolve 02, Quicklook Report*

23. Marine Corps Warfighting Laboratory, *Battle Griffin 02 Limited Objective Experiment,* by J.B. Stone, IV, Major, USMC, et al., April 2002

24. Navy Warfare Development Command, *Exercise Strong Resolve, Joint Venture HSV-X1, Final Analysis Report,* May 2002

Operations under Army Administrative Control, 20 March - 13 July 2002

25. U. S. Army, *Joint Venture HSV-X1 Snap Shot*: 20 MAR 02 - 13 JUL 02, undated, unclassified

Millennium Challenge/Fleet Battle Experiment Juliet, 21 July - 7 August 2002

26. Marine Corps Warfighting Laboratory, *Millennium Challenge 02 Limited Objective Experiment Joint High Speed Vessel Analysis Report,* by J. B. Stone, IV, Major, USMC, et al., August 2002
27. Joint Venture, HSV-X1, *Joint Venture (HSV-X1) Lessons Learned (Jul-Aug 02),* September, 2002

Related CNA studies and analyses

28. CNA Research Memorandum D0001406.A1/Final, *Concepts of Employment for a High-Speed Lighter,* by John F. Nance, Jr., et al., June 2000
29. CNA Research Memorandum D0005440.A1/Final, *World Ports: Pier Depth and Harbor Size—Part I: The Mediterranean and Black Sea,* by Daniel P. Roek, January 2002
30. CNA Information Memorandum D0005441.A1/Final, *World Ports: Pier Depths and Harbor Size—Part II: The Red Sea, Persian Gulf and India Coast,* by Daniel P. Roek, January 2002

List of figures

List of tables